2013 DOE Vehicle Technologies Review
Gasoline Ultra Fuel Efficient Vehicle

DELPHI

KIA

WERC

ENGINE RESEARCH CENTER UNIVERSITY OF WISCONSIN - MADISON est 1946

WAYNE STATE UNIVERSITY

ACE064
Merit Review DE-EE0003258

Keith Confer
Principal Investigator

17MY13

U.S. DEPARTMENT OF ENERGY

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Ultra Fuel Efficient Vehicle (UFEV) Project Overview

Timeline

- Project start: 9/1/2010
- Project end: 3/31/2014
- Percent complete: 75%

VT Programmatic Barrier

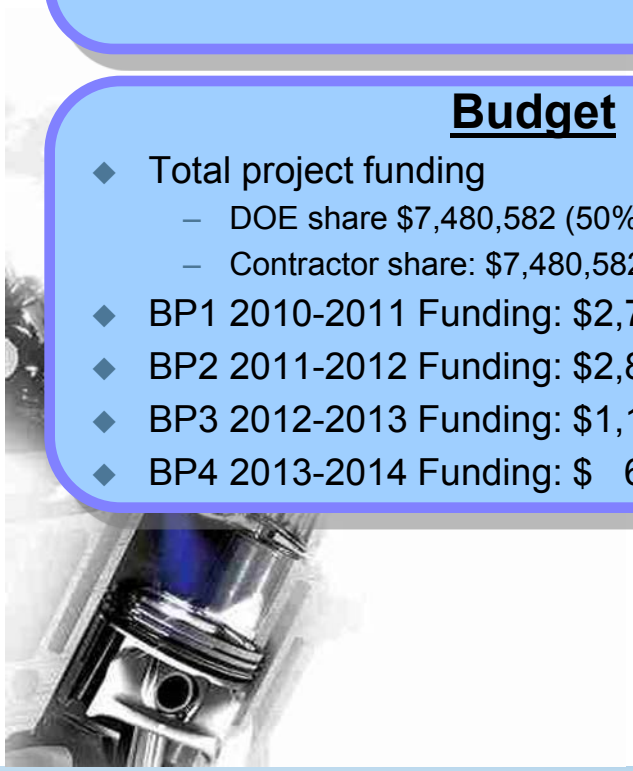
- Improve the efficiency of light-duty engines for passenger vehicles through advanced combustion and minimization of thermal and parasitic losses.
- Project primarily addresses VT Program Barriers:
  - A: Advanced engine combustion regimes
  - D: Effective engine controls

Budget

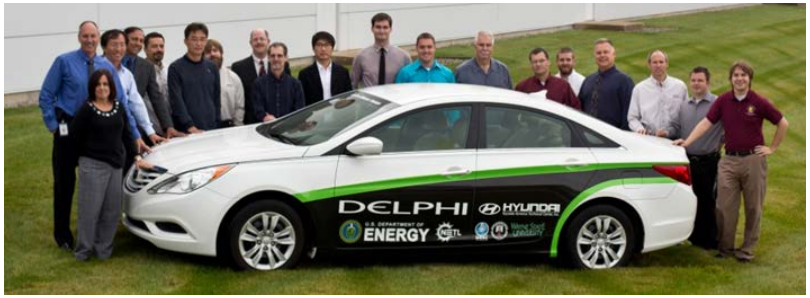
- Total project funding
  - DOE share $7,480,582 (50%)
  - Contractor share: $7,480,582 (50%)
- BP1 2010-2011 Funding: $2,788,205
- BP2 2011-2012 Funding: $2,837,265
- BP3 2012-2013 Funding: $1,169,418
- BP4 2013-2014 Funding: $ 685,693

Partners

- Delphi - Project Lead
- HATCI (Hyundai America Technical Center Inc.)
- WERC (Wisconsin Engine Research Consultants)
  - University of Wisconsin
- Wayne State University



Ultra Fuel Efficient Vehicle (UFEV) Project Collaboration with Other Institutions



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Project Lead

Auburn Hills, Michigan
Henrietta, New York

HATCI
HYUNDAI AMERICA TECHNICAL CENTER INC.

KIA

Superior Township, Michigan

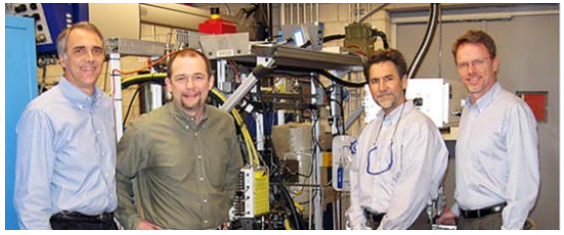
WAYNE STATE UNIVERSITY

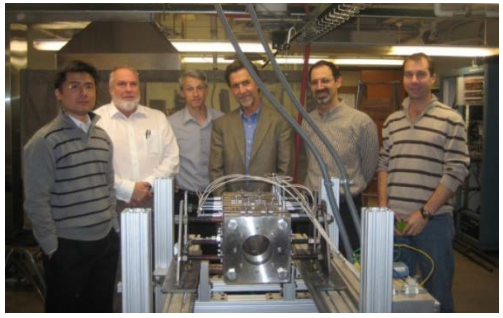
Detroit, Michigan

WERC
Wisconsin Engine Research Consultants

ENGINE RESEARCH CENTER
UNIVERSITY OF WISCONSIN - MADISON
est 1946

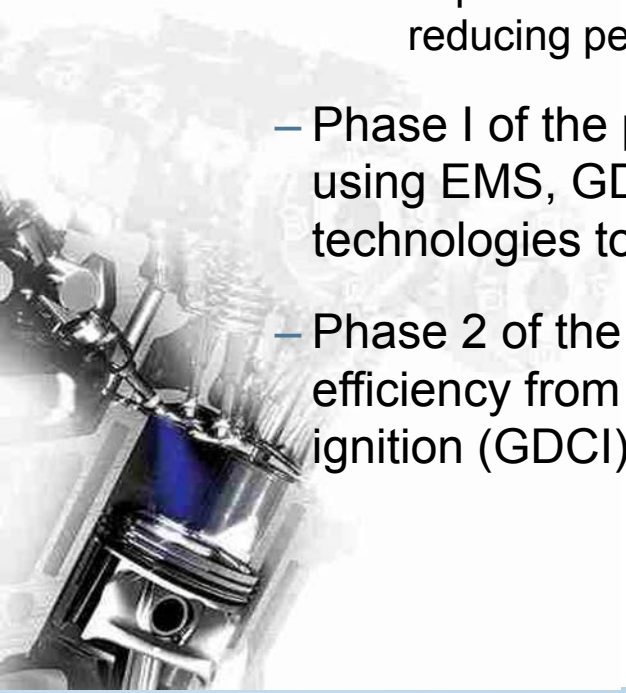
Madison, Wisconsin





Ultra Fuel Efficient Vehicle (UFEV) Project Relevance

- **Objective**
  - Develop, implement and demonstrate fuel consumption reduction technologies with an expert team comprising a Tier 1 automotive supplier, an automotive OEM and universities.
  - Targeted fuel economy improvement of > 30% vs. PFI baseline.
    - Improved engine and vehicle efficiency reduces GHG emissions by reducing petroleum consumption.
  - Phase I of the project concentrates on fuel efficiency improvements using EMS, GDi, and advanced valvetrain products in combination with technologies to reduce friction and parasitic losses – Near Term
  - Phase 2 of the project will develop and demonstrate improved thermal efficiency from in-cylinder combustion with gasoline direct compression ignition (GDCI) - Advanced Combustion



Approach / Strategy
Project Hardware Plan

Major Project Milestones

April 2010	June 2012	March 2014

Phase 1

Phase 1 Vehicle Demo

Phase 1 Loss Reduction Vehicle 1

Phase 1 Electronics & Controls Vehicle 2

Applicable Technologies

Phase 2 Vehicle Demo

Phase 2 Vehicle 3

Phase 2

GDCI SCE1 ***GDCI SCE2*** *GDCI Multi-Cylinder*

Phase 2 Engine Development

HCCI MCE

Phase 1 Accomplishments:
Vehicle 1 completed with project specific hardware

- **Vehicle Build and Integration of Technologies**
  - The first Phase 1 demonstration vehicle has been built and all calibration and testing completed.

Cooled EGR

Optimized Oil Pump

2011 Sonata 6MT, 2.4L GDi Theta II

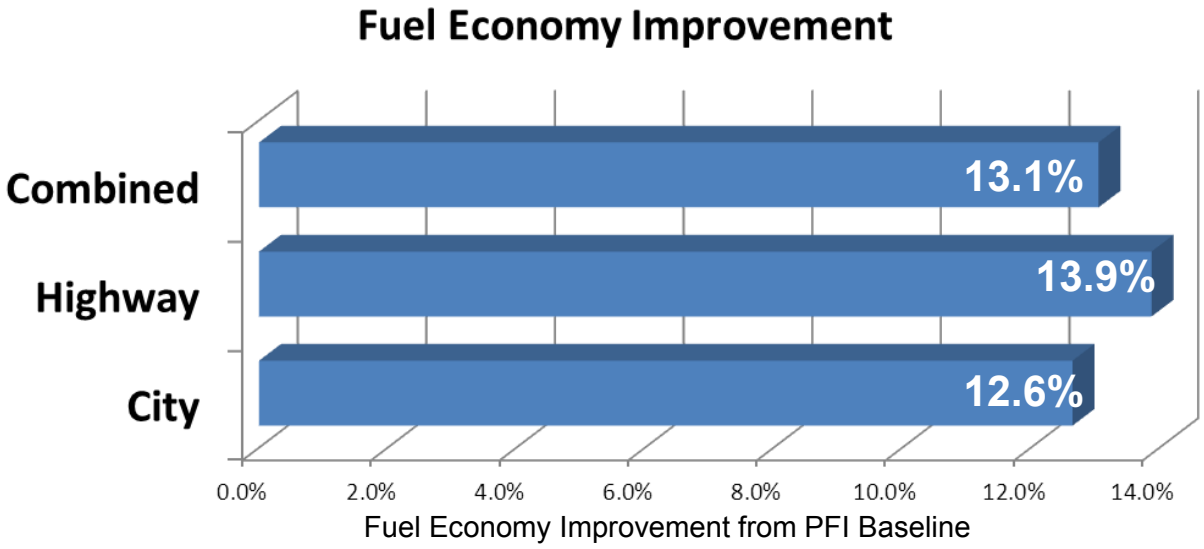
Rollerization

Engine Downspeeding and Friction Reduction

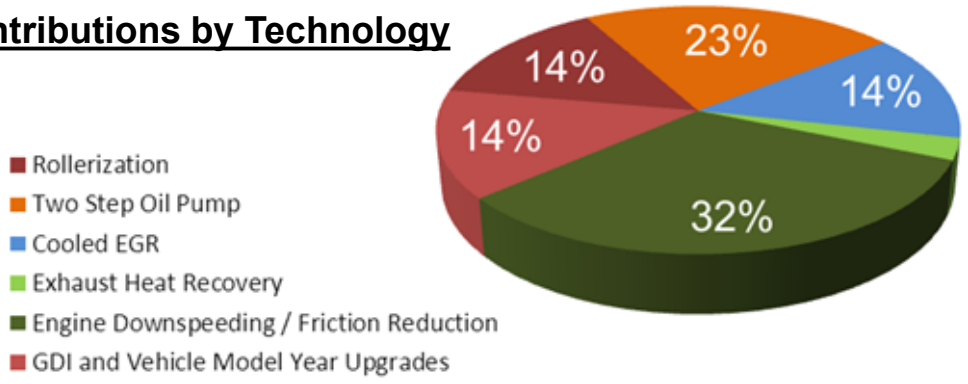
Exhaust Heat Recovery System

Heat Recovery and Friction Reduction Controls

Phase 1 Accomplishments: Completed
Vehicle 1 Test Results

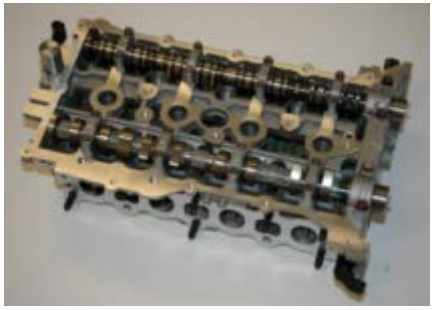


Estimated Contributions by Technology



Phase 1 Accomplishments:
Vehicle 2 completed with project specific hardware

- **Vehicle Build and Integration of Technologies**
  - The second Phase 1 demonstration vehicle has been built and all calibration and testing completed.



Variable Valvetrain

Cooled EGR

2011 Sonata 6MT, 2.4L Theta II

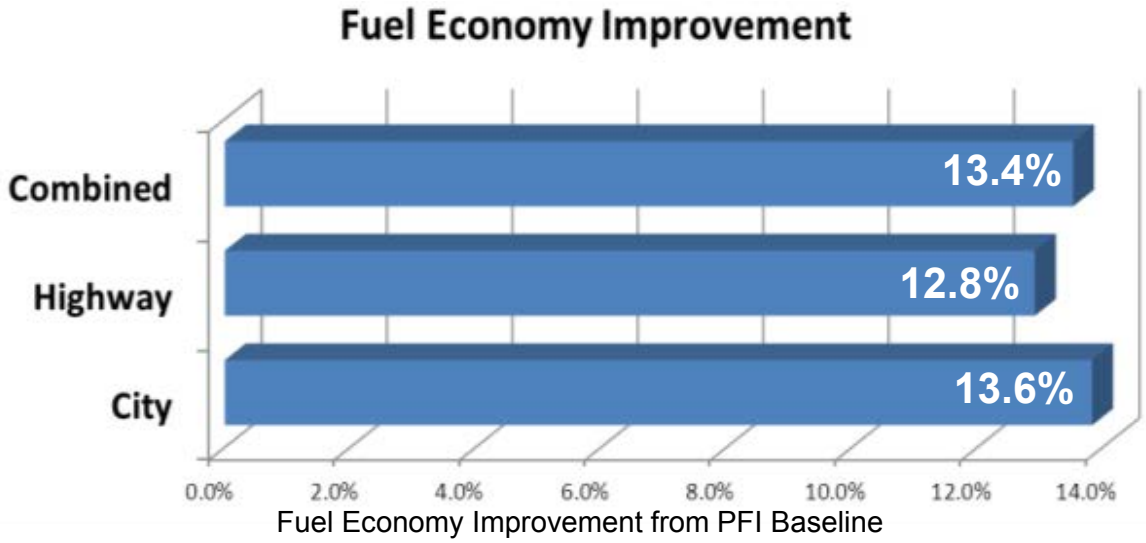
Delphi EMS
Controller
Control Algorithms
Calibration

Delphi ePhasers

Stop / Start

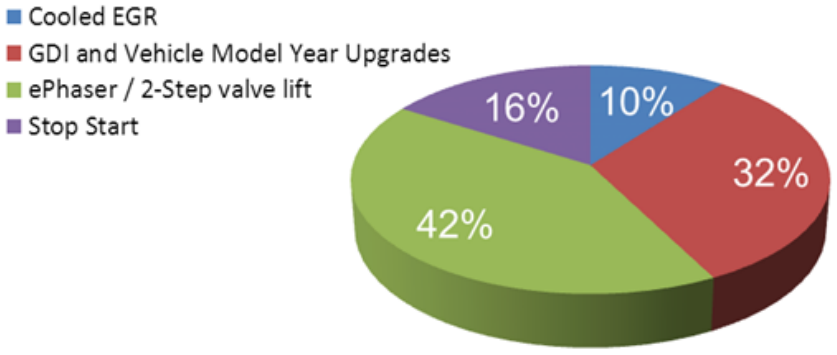
Delphi GDi Fuel System

Phase 1 Accomplishments: Completed
Vehicle 2 Test Results



Fuel Economy Improvement from PFI Baseline

Estimated Contributions by technology



Approach / Strategy
Project Hardware Plan

April 2010 | June 2012 | March 2014

Phase 1

Phase 1 Vehicle Demo

Phase 1 Loss Reduction Vehicle

Applicable Technologies

Phase 1 Electronics & Controls Vehicle

Phase 2

Phase 2 Vehicle Demo

Phase 2 Vehicle

GDCI SCE1

GDCI SCE2

GDCI Multi-Cylinder

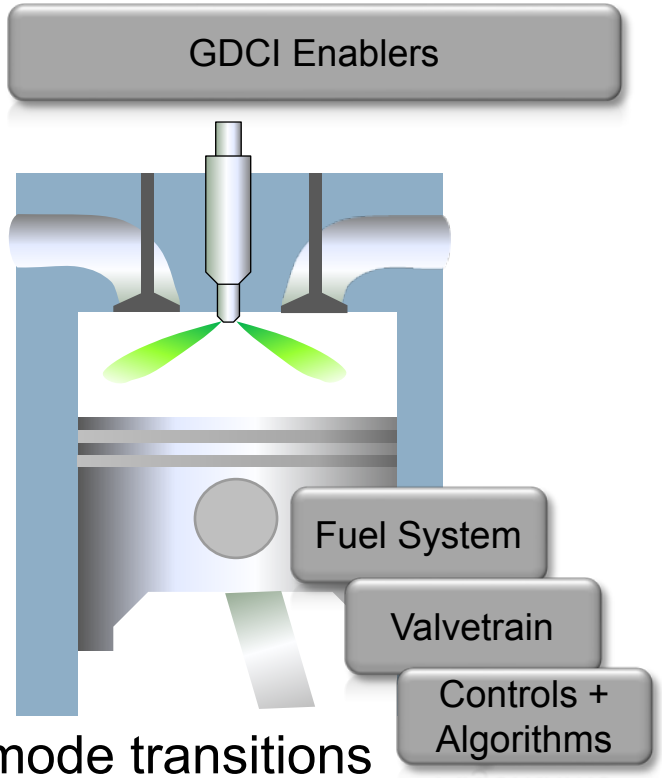
Phase 2 Engine Development

HCCI MCE

Approach / Strategy
GDCI Engine Concept

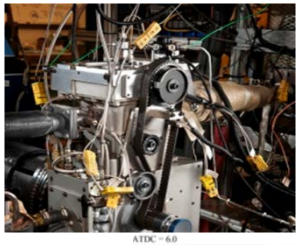
Gasoline Direct-injection Compression Ignition (GDCI)

- Gasoline partially-premixed compression ignition (PPCI)
- High compression ratio and lean for high thermal efficiency
  - No classic SI knock or pre-ignition
- 87 octane gasoline E10
- Fuel injection – key enabler
  - Central Mounted
  - Multiple Late Injections during compression
  - GDi-like injection pressures
- Valvetrain – continuously-variable
- Boosted and down-speeded
- Cooled EGR
- Controlled heat release – low noise
- Full time GDCI across speed load range – no mode transitions

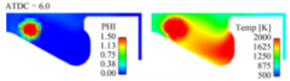


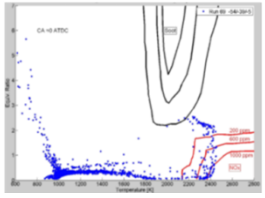
Accomplishments
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

- Conducted extensive single cylinder engine tests with advanced injectors, valvetrain and piston designs
- Refined simulations of spray, mixing and combustion processes (performed at WERC and Delphi with bench tests at U of W)
- Fabricated new GDCI engines
  - Including project specific cylinder heads, enhanced engine block, valvetrain systems, fuel systems, boost & air control systems
- Ran multi-cylinder engines on performance dynamometer and engine start cart
- Continued development of engine controls



GDCI Single Cylinder Engine





GDCI Multi-Cylinder Engine

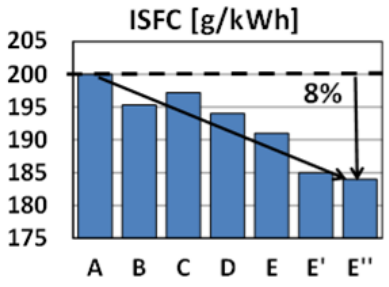
GDCI Multi-Cylinder Engine Start Cart for Controls Development

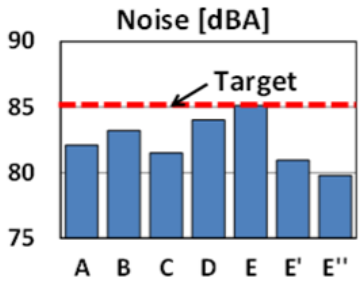
Accomplishments
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

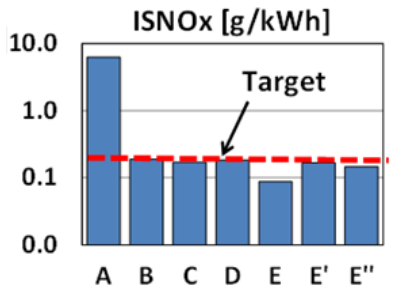
Tests on Hydra Single Cylinder Engine (1500 RPM - 6bar)

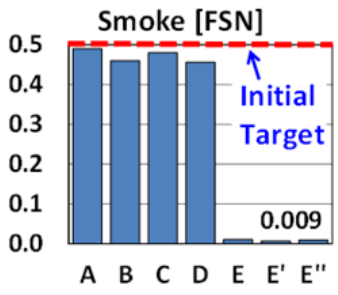
- Configurations A thru E'' were tested
- Configurations E'' performed best

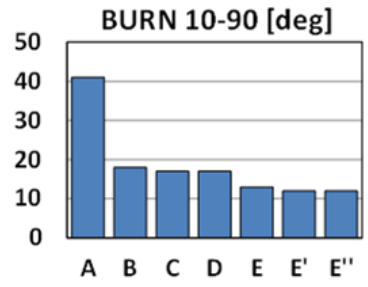
Test	Injector	Fuel	GCR	Piston	SR	EGR	MAP	Injection
A	A	E00	16.2	Diesel	3.1	45	1.8	Triple
B	B	E00	16.2	Diesel	1.7	45	1.8	Triple
C	C	E00	16.2	Diesel	1.7	45	1.8	Triple
D	D	E00	16.2	Diesel	0.6	45	1.8	Triple
E	E	E10	14.5	Diesel	0.6	30	1.8	Triple
E'	E	E10	14.5	GDCI	0.6	30	1.8	Triple
E''	E	E10	14.5	GDCI	0.6	0	1.6	Double

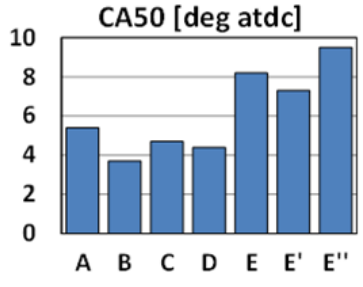


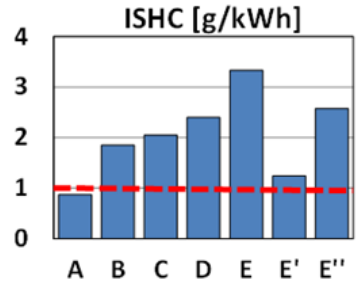


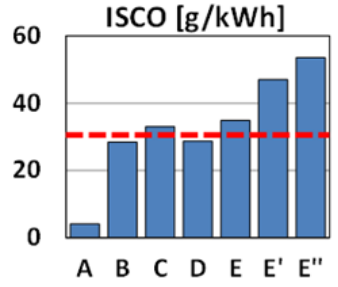












Accomplishments
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

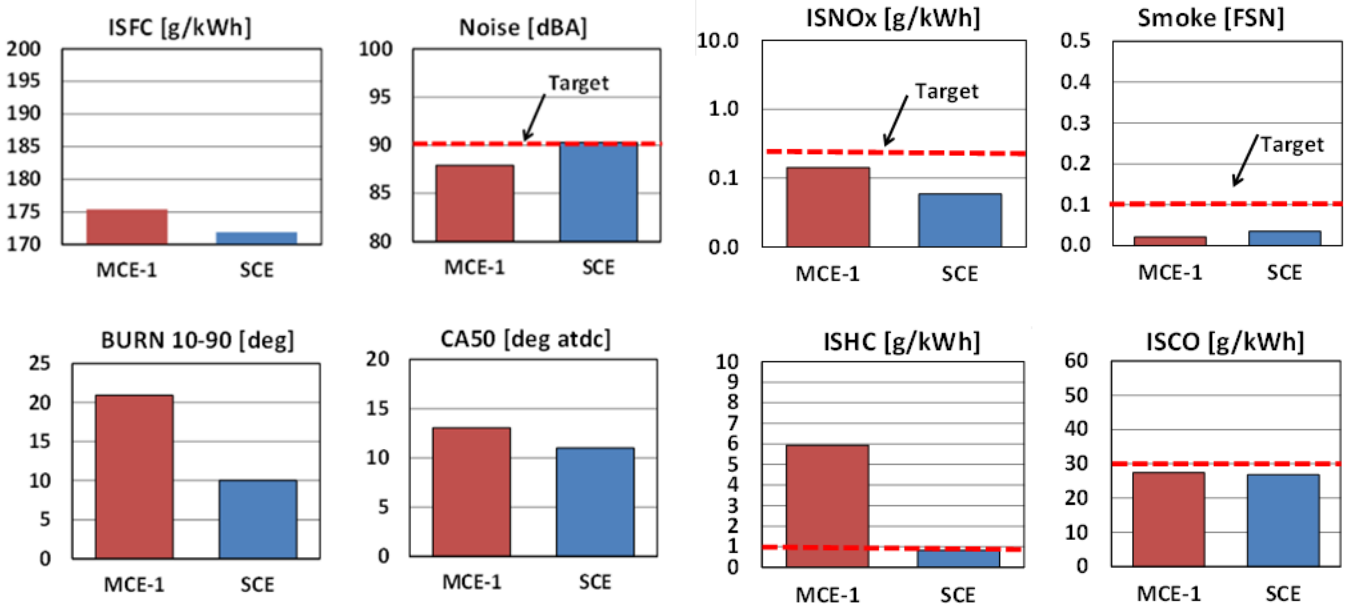
Multi-Cylinder GDCI Engines completed and running

- Purpose built for project
- 1.8L inline 4 cylinder
- 4 valves per cylinder
- 14.8:1 Geometric compression ratio
- Central-mounted DI Injector
- DOHC fully flexible valvetrain
- Variable geometry turbocharger, supercharger and two intercoolers
- Cooled EGR
- 87 Octane E10 Gasoline

Accomplishments
Phase 2 GDCI (Gasoline Direct injection Compression Ignition)

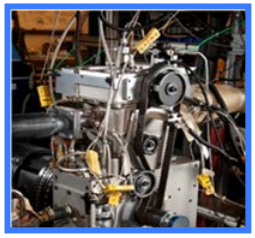
Preliminary, non-optimized MCE tests VS. SCE results (2000-11bar)

- Injector E was tested for both Multi-cylinder Engine (MCE) and Single Cylinder Engine (SCE)



MCE

VS



SCE

Strategy
Comparison of Efficiency Mechanisms

Efficiency Mechanism for Diesel & GDCI	Diesel	GDCI	Gasoline SI
Fuel Economy Benefit	25-30%	25-30%	Baseline
High Compression Ratio	~16:1	~15:1	~11:1
Unthrottled Operation (Pumping)	Yes	Yes	No
Lean Combustion (Gamma)	Yes	Yes	No
Negative Work in Pilot Injection	Yes	No	
Wall Losses with Swirl	High	Lower	

Accomplishments: GDCI Engine Controls

- Controls development engine running on start cart
- Controls development underway
  - GDCI controls structure developed
    - Flexible, distributed, multi-controller architecture
    - Integrates rapid prototyping, development, and production target controllers
  - Controls simulation
    - Transient engine simulation model completed
  - Bench Testing
    - Component and subsystem level testing completed on many of the subsystems
  - System integration
    - Start Cart build completed and GDCI engine installed
    - GDCI engine controls integrated
- Vehicle integration
  - Controls integration plan defined
  - Integration process initiated
  - Vehicle preparation work complete
  - Hardware being built / procured

Phase 2 GDCI Start Cart

Future Work
UFEV Project 2013-2014

- **Phase 1**
  - **Complete**: Completed on time in 2012
- **Phase 2**
  - **SCE Testing**: Advanced injection and valvetrain strategies will be refined over the speed load range using a project specific head.
  - **Simulation**: A variety of simulation tools for injection and spray development, combustion system, and valvetrain systems will be applied to achieve minimum NOx and PM emissions.
  - **MCE Testing**: MCE testing will continue throughout the project in support of powertrain integration, component refinement, steady state controls and calibration
  - **Controls**: Advanced and transience controls hardware and software will be developed using HIL Bench, simulation, and start cart, followed by transfer to the vehicle.
  - **Demonstration Vehicle**: A Phase 2 demonstration vehicle is currently being built. To be used for vehicle-level controls development, final calibration and performance testing.

Summary
Ultra Fuel Efficient Vehicle (UFEV) Project

- **Objective**
  - Develop, implement and demonstrate fuel consumption reduction technologies with a targeted fuel economy improvement of > 30% vs. PFI baseline.
- **Project**
  - The project team, with representation from universities, research, systems level automotive supplier and automotive OEM, is integrated and fully functional.
  - The project is on schedule and is meeting budget targets.
- **Phase 1**
  - Complete with demonstration vehicles showing excellent fuel economy results.
- **Phase 2**
  - Simulation and single cylinder engines have been used to refine the GDCI combustion process and develop fuel injection hardware and strategies. SCE test results have demonstrated very low fuel consumption and emissions for GDCI.
  - A new multi-cylinder GDCI engine has been designed and several engines have been fabricated. Theses engines have shown good correlation to the single cylinder development engines and have successfully demonstrated full speed / load capability including idle.

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Thank-You

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